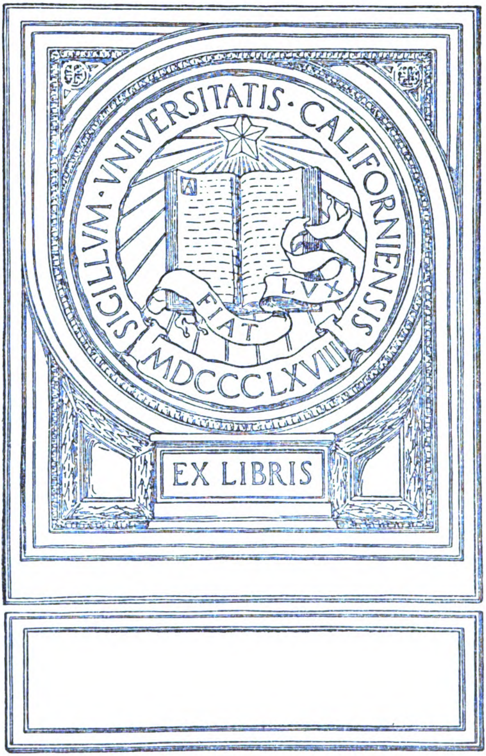
THE AIR CADET'S HANDBOOK

ON

HOW AN AEROPLANE FLIES

BY

C. G. [illegible]REY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ON

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ON

HOW AN AEROPLANE FLIES

BY

CHARLES G. GREY

(Founder of *The Aeroplane* in June 1911 and editor until September 1939, editor of *All The World's Aircraft* since 1916)

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WOKING

To My Son

JOHN

The Author hopes that Mr. Clark's elegant sketches will enable those who cannot grasp the verbal explanations to understand just what does happen to an aeroplane.

CONTENTS

CHAPTER ONE

First Principles

In these days every schoolboy knows how to fly an aeroplane and is sure that if he were left alone in the cockpit and given a little time in which to get to know the fantastic number of gadgets on the dashboard he would be able to fly it. But the curious thing is that so many who know how to fly an aeroplane, and some who fly quite well, have little idea of how or why an aeroplane flies.

The first thing to understand is that air is very compressible but at the same time very resilient. Which means that if you compress air hard and then let it go you will get a large amount of expansion in return. Which is why rubber balls bounce and why pneumatic tyres add to the comfort of a car.

Also air is very sticky—viscous is the scientific word for it. In proportion to its density, air is rather stickier than treacle.

Another elementary fact to remember is that the weight of the air on the Earth's surface is such that it produces a pressure on everything in it of 15 pounds per square inch. If you go

down a mine the pressure is higher still, and as you go higher the pressure becomes less.

At roughly 15,000 feet above sea-level the atmospheric pressure is about half what it is at sea-level.

Also the pressure of the air, and consequently its weight, varies according to the state of the weather. In stormy weather the pressure is lower than it is in fine weather—which is why the barometer falls and rises.

One may get a simple and useful idea of the atmosphere in which we live by picturing ourselves as a species of monster which walks about at the bottom of a vast ocean of air but is unable to swim in it, like crabs and lobsters which crawl at the bottom of the sea. For good or evil we have discovered how to fly instead of crawl.

THE PLANE WHICH IS NOT

Like many words in English, "aeroplane" has grown to mean something which it describes wrongly. A plane surface in practical engineering means a surface which is, as nearly as may be, perfectly flat—whereas an aeroplane depends for its ability to fly on the fact that nothing about it ought to be flat.

In the *Glossary of Aeronautical Terms* issued as

lately as August 1940 by the British Standards Association, a Government-supported organization, the word "aeroplane" is defined as "a flying machine with plane(s) fixed in flight."

A "landplane" is "an aeroplane provided with means for normally arising from and alighting on land." And a "seaplane" is "an aeroplane provided with means for normally rising from and alighting on water."

Thus an official committee of aeronautical scientists has committed itself to the use of the word "plane" first to describe the wings— "with planes fixed in flight." Secondly, it is used to describe the whole aeroplane. Thirdly, to complicate matters, a "ship-plane" is "any aeroplane specially adapted for rising from and alighting on a ship's deck."

The word "sailplane" is officially given for a motorless aeroplane which can soar level, or rise, on upward air-currents.

Furthermore, a "monoplane" is defined as an "aeroplane or glider with one main plane." And a "multiplane" is "an aeroplane or glider with two or more main planes one above another."

In workshop or aerodromes, the people who build or handle aeroplanes commonly talk of the right or left, or starboard or port, and some-

times the upper or lower plane of a biplane. To be more correct one should speak of them as the right or left, or upper or lower, wing.

AEROFOILS

Our scientists recover their accuracy when they describe the word "aerofoil" as "a wing-shaped body whose main function is to produce lift." Its possibly minor but equally important function is to keep the body of the aeroplane in the air, so it is often a complicated engineering structure.

An aerofoil or plane has "camber," which is officially "curvature of the centre-line of an aerofoil section. More generally, the curvature of a surface."

In aeroplane design the camber of an aerofoil is so important that if your wing has a bad aerofoil section no amount of horse-power will make your aeroplane good.

The word aerofoil is from the French word *feuille*, meaning a leaf. We use the word commonly when we talk of tinfoil or goldfoil or trefoil (three-leaf clover).

But remember one basic fact—an aerofoil, or cambered wing, is simply a cambered or curved wing-surface properly streamlined.

SKIN-FRICTION

If you take a flat plate (or a plane surface properly so called) and slide it through the air horizontally so that it cleaves the air straight, or if you fix your plane surface and blow the air straight towards the edge, you would expect to get no drag from the air. But because of the pressure of the air all round and because the air is sticky, the air will drag along the top and bottom surfaces of your plane and will cause what is called skin-friction, or surface drag.

Skin-friction is the force which tends to delay the progress of any body through a fluid in addition to the delay caused by direct resistance (head resistance). Its amount depends on the density of the fluid and on its viscosity, or stickiness.

For example, water, lubricating oil, and treacle are all of about the same density. If you take a table-knife and draw the blade edgewise and vertically through water you feel no resistance to speak of. If, on the other hand, you draw the blade in the same way through treacle, you feel a strong resistance. That is not head-resistance, for the treacle itself offers little resistance to the knife's edge. It is simply that the blade has become wet with treacle, and

other molecules of treacle stick to the layer which is stuck to the blade, and form a viscous drag as you draw the blade along.

That drag is skin-friction. The proportion of density of air to water is, I believe, about 800 to 1. But air is much more viscous than water, and so the skin-friction on a large flat surface is considerable.

Professor Frederick Lanchester, years ago before anybody flew, said that skin-friction increases as the square of the velocity—if you double the speed you multiply the friction by four. But at speeds of 300 m.p.h. or more resistance is supposed to go up as the cube of the speed, which means that twice the speed means *eight* times the resistance.

An interesting side-light on skin-friction generally is given in a remark by Dr. Zahm, a pioneer of experiments in America. Apparently, whether the plane surface on which he experimented was covered with cork or buckram or glazed or unglazed cambric, the amount of friction seemed to differ very little—which is contrary to more recent experience of matt or varnished surfaces on high-speed aeroplanes. Dr. Zahm says,

"The fact that such a variety of materials exhibit practically the same friction seems to

indicate that this is a shearing force between the swiftly gliding air and the comparatively stationary film adhering to the surface or embedded in its pores. If, as seems to be true, there is much slipping, this means that the internal resistance of the air is less at the surface than at a sensible distance away."

On the other side, Dr. A. P. Thurston, of London University, describes air friction as a manifestation of a force which he calls "Kinematic Dispersion," which is analogous to the effect of an elastic or resilient body hitting another and glancing off it. As he put it, "If one can imagine a railway train running along and being pelted all the time with heavy balls which hit it and bounce off again, one can realize that the impact of these balls, and the exertion of the force necessary to repulse them, and at the same time to give them an impulse in a forward direction, would in time slow the speed of the train. So in a body travelling through the air. It is being continually pelted with molecules of air, and the more acute the angle at which they hit the body, the more they are retarded."

Yet another theory is that the treacly but resilient air sticking to the surface creates a lot of little rollers of air in contact with the surface

and with one another and with the layers of air outside them. Thus one gets a turbulent flow along the surface which changes into straight streamlines running in layers, or laminar flow, as scientists call it.

CHAPTER TWO

Streamlines

Now let us consider streamlining as such. First I had better describe briefly what is a wind-tunnel—because wind-tunnels have been and are used so largely in experiments in aero-dynamics. Originally a wind-tunnel was just a long tube or a square-section box in which a model or other article with aero-dynamic qualities was slung or held up on an arm whose movements could be measured, while a stream of air at a known speed was blown over it by an electric fan. The rotating blades of the fan caused the air to rotate inside the tunnel or tube, so the fan was put behind the model and sucked the air past it, and a honeycomb grid was put at the front of the tunnel to straighten out the air streams as they came in.

In some of the modern wind-tunnels, which are big enough to take in a whole aeroplane, air can be sucked through the fan at more than 100 m.p.h.

The simplest demonstration of streamlining is one of which operators of small wind-tunnels are fond. In the wind-tunnel they put a disc about the size of half-a-crown on one end of an

arm which is fixed on a pivot in the tunnel. At the other end is a streamline shape, which looks like a young airship, whose greatest diameter is that of the disc.

An ignorant person might think that the resistance to the air of the airship's large body should be greater than that of the simple flat half-crown. But as soon as the draught is turned on, the disc goes right back and the airship shoots forward, showing that the resistance of the streamlined body is much less than that of the disc. One can show the reason for this diagrammatically.

When the air hits the disc the first mass of molecules is compressed and forms an elastic cushion off which the succeeding molecules bounce, and flow over the edge of the disc into the region of dead air behind it. And so the disc sets up a terrific drag.

If you fit a nose on the disc, like the nose of an airship, the air will bounce off the nose and will flow down in a turbulent mass into the vacant space behind the disc. But if you put a tail behind the nose, so that the disc is embedded in an airship-like shape, then the air which bounces off the nose, like the bow-wave of a ship, comes back on to the tail of the streamline body and helps to push it forward.

If you were to put a pressure-gauge out through that streamline body at various points you would find that at the nose the air pressure was above 15 lb. to the square inch. At the maximum diameter, where the disc is concealed, the pressure would be a great deal

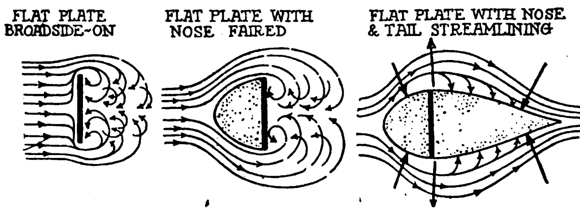


FIGURE I

less than 15 lb. to the inch. And down towards the tail the pressure would again be more than 15 lb. to the inch. The effect is rather as if one held an orange-pip between one's lips and then, by compressing the lips, shot the pip out.

That is the principle of every streamline. Naturally there is air flowing along the surface of the body all the time, and although the pressure is decreased round about the maximum diameter, nothing like a vacuum can be created. In conversation this region of decreased pressure is often described as a "partial vacuum," although that is a scientific inaccuracy.

Similar things happen in water. But because

water is incompressible—hence the fact that hydraulic gadgets work as they do—a shape which is precisely correct for a water streamline would be quite wrong for an air streamline.

BURBLING

Streamlining both for air and water is complicated by the fact that there can only be one streamline shape which is absolutely right for any given body at any given speed. The whole idea of a streamline shape is that it bounces the air off its nose and is so shaped aft that the air pressure returns and pushes it forward.

If your streamline is too fat and the after part, or the "run aft," is too short, or too stumpy, then the air will break away and become turbulent and cause drag, as it does behind the flat disc.

The accepted term for this breaking away of the air is "burbling." The latest Standard Glossary omits the word "burble"—which was first popularized in English in Kipling's *Stalky & Co*. The nearest it gets is "turbulent flow." And I can find no definition which precisely describes what every aeroplane designer knows as the "burble-point," at which the air becomes turbulent.

If you lengthen the run aft, then, with the increasing speed the air which has bounced off will return round the tail of the body and push it forward and continue its own flow without burbling.

The shape of this run aft is so important that one of our most famous aeroplane designers said to me years ago that you could put anything you liked in front of the maximum diameter of the body of an aeroplane but you had to be mighty careful what you allowed to stick out aft of the maximum section.

CHAPTER THREE

How an Aeroplane Lifts

The first thing to remember about a lifting aerofoil is that most of the lifting is done by the *upper surface*.

The earliest attempts at an aerofoil shape were just thin wings with the leading edges bent over in a curve. Then the idea developed of making the lower surface of the wing into a curve of its own, different from the upper surface so that the two together should form a reasonable streamline round the spars. And from that was developed the aerofoil section as we know it to-day, which is the result of extensive practical tests, followed by highly scientific mathematical calculation checked up against elaborate wind-tunnel experiments.

HOW THE UPPER SURFACE LIFTS

At this point perhaps I had better show you a simple experiment which proves that the upper surface of an aeroplane does most of the lifting.

Take a sheet of fairly stiff notepaper, say 6 inches long and about 4 inches wide. Fold it

crosswise 2 inches or perhaps less from the end, thus producing a flat surface roughly 4 inches square with a flap at one end 4 inches long and 2 inches wide. Now bend the flap backwards and forwards until it becomes limber, like a hinge. Next curve the 4 by 2 flap till it is

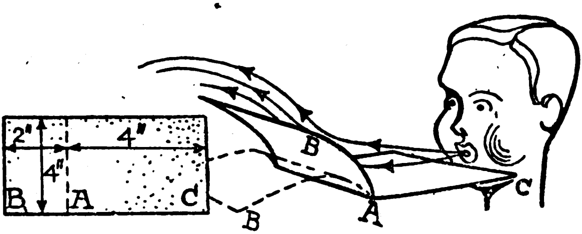


FIGURE 2

roughly an arc of a circle—a much larger circle than it will take into its 2 inches—that is to say, the 4 by 2 flap ought to be something like the shape of a heavily curved, or cambered, wing of an aeroplane.

Then hold the edge of the paper close to the chin, below the lower lip, and blow along the top of the paper so that none of the draught goes under the flat paper but all along the top. You will find that the curved flap will rise and stand upright, as shown by the rise of the dotted curve in the sketch, and will hold steadily there so long as you go on blowing.

If you place the flat part of the paper

above your lips and blow underneath it, the flap will rise because of the direct pressure against it, and it will keep on rising and falling back in the draught. But it will never rise to the same height as it will when blown at from above.

THE FIRST AEROFOILS

The first record that we have of knowledge of the curved aerofoil, wing or plane, is that in 1808, more than 130 years ago, Sir George Cayley, a landed gentleman who had scientific leanings, made model gliders which had wings of curved sections. And, like Leonardo da Vinci, some three hundred years earlier, he knew of the possibilities of the propeller or air-screw. He also invented a rotary motor driven by gunpowder.

The next important step towards making an aeroplane fly was that of Messrs. Henson and Stringfellow, of Chard, in Somerset, in about 1840. Their large steam-driven monoplane model is in the South Kensington Museum to-day. It has scientifically braced cantilever wings, a streamline body and twin propellers.

The importance of the next step in development has even now not been fully recognized—

Mr. Horatio Phillips, a member of the then young Aeronautical Society, experimenting in 1885, settled the section of wing which gives the most lift, and proved the possibilities of the multiplane, or Venetian blind, idea.

Sir Hiram Maxim, inventor of the Maxim gun, the father of all machine-guns, arrived at the same section of wing by different experiments, as did Mr. José Weiss, an Alsatian artist who lived near Arundel.

Roughly, the section on which they all agreed was one in which the highest part of the curved, or cambered, upper surface is not more than one-third of the distance between the nose, or leading edge, and the tail, or trailing edge, of the section, and the lower surface of the nose must come down a little below the leading edge before running aft to the trailing edge or curving up and down again. This type of leading edge was generally known in the early days of flying as the "Phillips entry."

SEEING THE SPRAY

Here I must put on record a remark by the late Anthony Fokker, the great Netherlands aircraft designer and constructor, whose aeroplanes did so much harm to us in the last war

and did so much for Civil Aviation between wars. He said to me that a boat designer had the advantage that he could see the spray and so could see whether his boat was clean and efficient or not. And he added, "*If one could see the spray in the air*, most aeroplanes would be condemned as hopelessly inefficient."

The difference between a good aeroplane designer and a bad one is often the ability of the good designer to make a mental picture of the spray in the air.

Anthony Fokker, who built many multi-motor aeroplanes, further remarked that no ship-designer who wanted to increase the speed and power of his ship would think of sticking his extra power-plant in the water on a couple of outriggers, as we put the outboard motors of an aeroplane protruding from the wings.—A point to be noted.

SPAN AND CHORD

Here I had better introduce the words "span" and "chord" and "aspect-ratio."

The span of an aeroplane is the distance between the tip of one wing and the tip of the other.

The chord is the distance between the leading

edge and the trailing edge in a straight line, irrespective of the curvature of the aerofoil.

The aspect-ratio is the number of times the chord will divide into the span. That is to say, if the span be 42 feet and the chord be 6 feet, then the aspect-ratio will be 7 to 1.

As a general rule, the higher the aspect-ratio the more efficient is the wing. The sail-planes which so interest students of aviation owe their efficiency largely to their enormous aspect-ratio.

About 1890 Mr. Phillips built a flying-machine with a steam-engine, which had a number of long narrow aerofoils in a frame, one above the other, like a Venetian blind. It lifted an enormous weight in proportion to its power at an absurdly low speed. But he was handicapped because he could only make his experiments round a circular track on which the aeroplane was kept by steel rods connected to a central pivot.

To-day many believe that by using supplementary aerofoils of high aspect-ratio above and below the wings of aeroplanes of normal appearance, which aerofoils could be retracted and extruded at will, as retractable undercarriages are, a great addition could be made to the lift of aeroplanes when taking off, and

that their speed could be much reduced when landing.

The familiar Handley Page slots on the leading edges, and the slotted flaps and Frise ailerons on the trailing edges of the wings of the highly successful Handley Page Hampden bombers, are examples of what can be done by the application of that idea.

Mr. F. G. Miles, the designer of the Magister and Master, experimented with triplane flaps under the wings before the war and achieved remarkable results. The N.A.C.A. (National Advisory Committee for Aeronautics), at Washington, U.S.A., has made similar discoveries.

At the Reims Aviation Meeting in 1909, M. Blériot, the first man to fly the English Channel and to win the prize for the fastest lap of the 10 kilometre aerodrome, cut about a foot off the trailing edges of the wings of his No. 22 machine, thus raising the aspect-ratio, though reducing the surface. And he flew much faster with the same weight and the same power.

This phenomenon has been re-discovered within the past couple of years by the Consolidated Aircraft Co. in America, whose Davis wings have an abnormally high aspect-ratio.

THAT "PARTIAL VACUUM"

The accompanying diagrams show what we might see if we could see the spray or the streamlines of air. As the wing ploughs through the air, or the air in the wind-tunnel flows past the wing, it hits the downward-curved nose and is deflected upwards, just as water is thrown out by the bow-wave of a ship. Because an absolute vacuum is impossible, a certain amount of the air at lowered pressure flows along the top of the plane. But underneath the bow-wave, as one may call it, there is a volume of much reduced pressure.

In other words, the wing or aerofoil is sucked up by this volume of reduced pressure on top of the wing. At the same time a certain amount of direct pressure is given to the lower surface of the wing so long as it is flying at a positive angle to the air.

Professor Melvil Jones, who was the leading authority at Cambridge University on aerodynamics until he rejoined the R.A.F. in this war, stuck pieces of wool to the upper surface of the wings of various aeroplanes and used to go up as a passenger carrying a kine-camera with which he took photographs of the behaviour of these wool-tufts as the machine made different manœuvres.

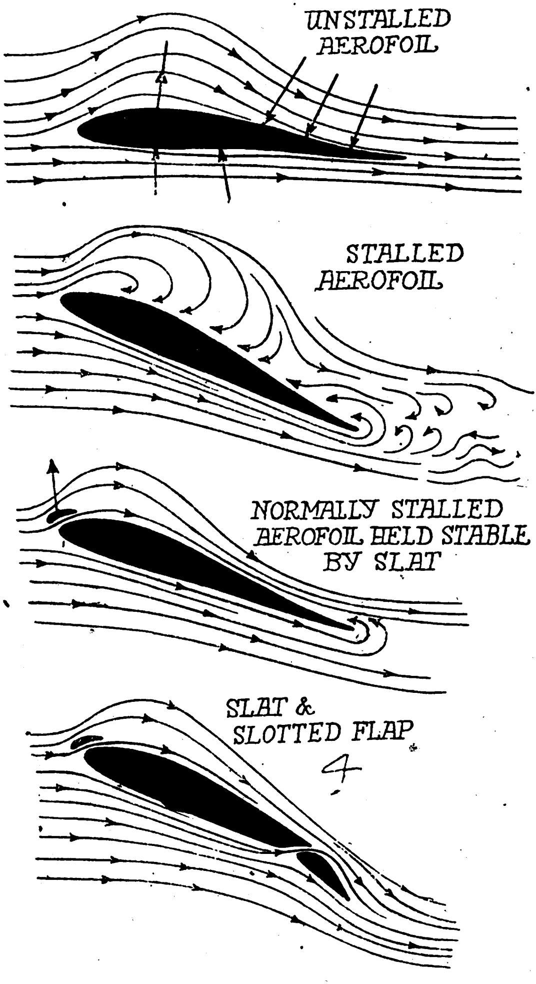

UNSTALLED
AEROFOIL
STALLED
AEROFOIL
NORMALLY STALLED
AEROFOIL HELD STABLE
BY SLAT
SLAT &
SLOTTED FLAP
4

FIGURE 3

Those who watched these experiments said that Professor Jones was one of the bravest men they knew, for he used to hang half-way out of the cockpit of an aeroplane winding away coolly at the camera as the machine stalled and fell away from under him.

His results agreed precisely with those of Piffard in 1908–9 and of S. F. Cody, that much-loved pioneer of British Aviation and a citizen of the U.S.A., who invented man-lifting kites which were taken up by our Army. In 1908–9 he built an aeroplane which was probably the first aeroplane to fly in this country.

CHAPTER FOUR

Stalling

Now, every aerofoil has an angle to the air at which it gives the best lift, and the best speed. By increasing the angle you may get more lift out of the wing because it will, so to speak, handle or deal with a greater weight of air. But you will reduce the speed, because you will increase the drag of the wing and tail.

As the angle of the wing to the air-flow increases, naturally the flow of the air over the top of the wing will alter. Finally a point will be reached when the air will refuse to follow the curve of the upper surface and will break away and become turbulent, just as it does behind a flat plate or a badly streamlined body. This is the "burble-point" of the aerofoil—just as one gets a burble-point round a streamline body.

When the air burbles over the leading edge the lift goes out of the plane, the nose of the machine drops, and, according to the shape of the aerofoil and of the fuselage, a longer or shorter dive will be needed to pick up flying-speed and to get the machine under control again. That is called stalling.

SLOTS AND SLATS

Somewhere in 1920 the experimental department of Handley Page, Ltd., discovered that if you put in front of the leading edge a slat, like a slat out of a Venetian blind, only curved like the leading edge of the wing, and put it just the right distance away from the leading edge, the slat will act as an aerofoil and, if the main portion of the aerofoil becomes stalled, the air, guided by the slat, will flow through the slot between the slat and the leading edge, and, guided also by the air-flow over the top of the slat, will flow on down the main aerofoil without burbling.

In that way the lift of the whole wing can be enormously increased, because the wing can get hold of the extra volume of air covered by the increased angle to the airflow without the air burbling and letting the wing stall.

Just about the same time when the Handley Page wind-tunnel crew were doing their experiments Dr. Lachmann, an aero-dynamic scientist in Berlin, who had been a pilot in the German Air Force until the end of 1918, had invented much the same thing.

Mr. Handley Page, instead of going in for costly litigation, wisely engaged Dr. Lachmann

into the service of Handley Page Ltd. He remained in this country and contributed to the development of the slot till he was interned at the outbreak of war.

An interesting point is that although the Handley Page slot was introduced to the world in *The Aeroplane* newspaper in March 1920, we have never developed the use of the slot as we might have done in this country. Messerschmitt uses slots on his fighters and so do the Savoia people on their bombers, but we do not, other than on the Hampden and the Westland Lysander Army Co-operation machine.

Members of the Air Training Corps will be interested to know that when Air-Commodore Adrian Chamier came back from commanding the R.A.F. in India and was appointed Director of Technical Development at the Air Ministry under Air-Marshal Sir John Higgins, one of his first acts was to have slots fitted to the Bristol Fighters, which were used as General Purpose machines, or maids-of-all-work, mostly overworked and overloaded, in India and the Middle East, and thus saved many lives.

Naturally slots will not completely save an aeroplane from stalling. If the tail of the machine, and with it the trailing edge of the aerofoil, be depressed enough, then the slat

and the slot will themselves stall. But long before they reach that point the whole aeroplane will begin to sink, but still under lateral control with the wings horizontal.

FLAPS

A companion fitting to the slot on the leading edge of an aerofoil is the flap on the trailing edge. Flaps, or what amounted to the same thing, pulling down the trailing edge of a wing to increase lift, are an old device in aviation. But the first scientific adoption of the flap was introduced by Mr. C. R. Fairey in 1919. His idea was to increase the camber, and therefore the lift, when gliding in slowly to land or when taking off.

Somewhere about 1924, when hardly anybody except Mr. Fairey had used flaps, several patents were taken out in the United States for different types of flaps.

The Lockheed Co., now well-known as the makers of the highly esteemed Hudson used by our Coastal Command, produced the Fowler flap which slides out backwards from under the trailing edge of the aerofoil, thus increasing the area as well as increasing the angle to the air.

Mr. Arthur Gouge, of Short Bros., patented another form of sliding flap.

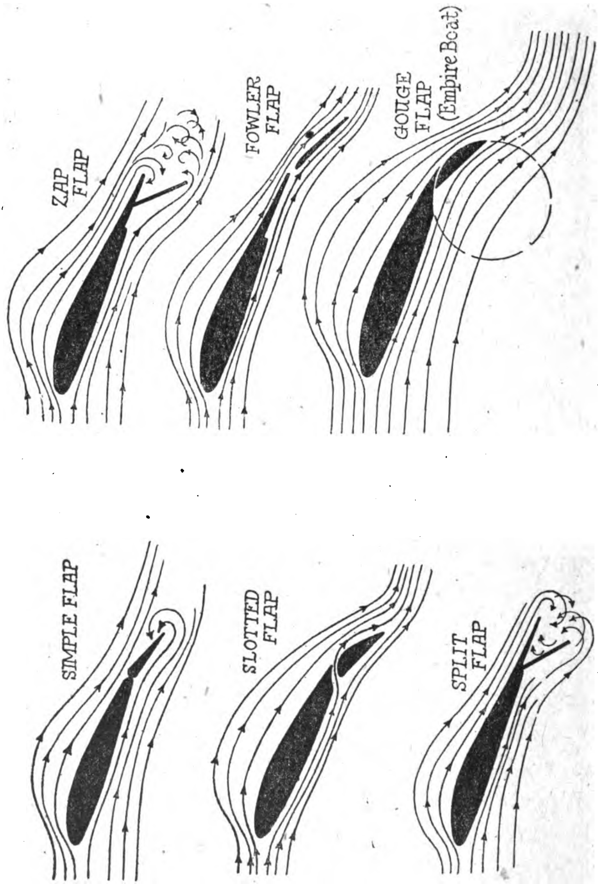

SIMPLE FLAP
SLOTTED FLAP
SPLIT FLAP
ZAP FLAP
FOWLER FLAP
GOUGE FLAP (Empire Boat)

FIGURE 4

Mr. John Northrop, one of the best American designers, produced the split flap, which was pulled down underneath the trailing edge and created turbulence in the angle between the trailing edge and the flap, and was a most efficient brake. But it was a hindrance in getting off, unlike the Fowler flap.

Mr. Frise, of the Bristol Co., much about the

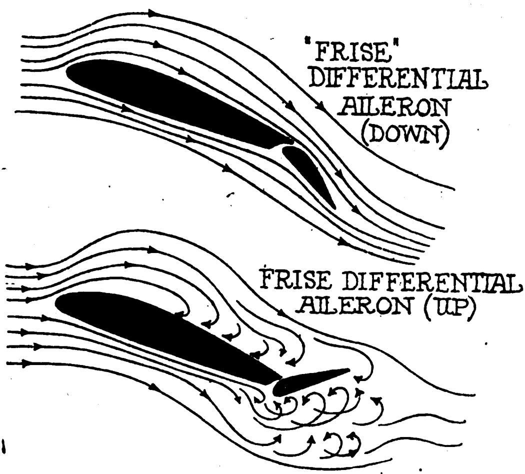


FIGURE 5

same time produced the Frise aileron, or flap, which is itself a part of the trailing edge of the wing, and when pulled down makes a slot between the back edge of the aerofoil and the

leading edge of the flap. Several firms in America now use it.

Yet another variety of the flap is the little supplementary wing used by the Junkers Company. When it is allowed to trail naturally

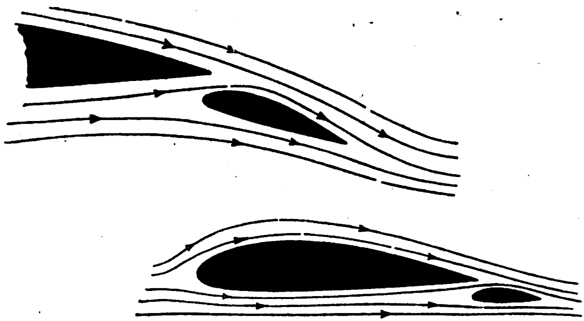


FIGURE 6

THE JUNKERS WINGLET

in the air it adds to the total lift of the wing and does not add much to the drag, or head resistance. When it is pulled down like an ordinary flap the effect is much that of the Frise flap, as the space between it and the main aerofoil acts as a slot. It is very effective in getting off and landing.

CHAPTER FIVE

Lateral Control

In the earliest days of aeroplanes, such as the Wright Brothers and Blériot, aeroplanes were prevented from heeling over sideways and capsizing by warping the wings. The front spar was anchored to the fuselage or body above and below by wires. The part of the wing aft of the front spar was moveable by pulling down the aft spar, which twisted the wing and gave it extra lift.

At the same time the Farman Brothers in France, who were making big biplanes of what we called the box-kite type, got their lateral control by cutting away pieces of the trailing edge behind the aft spar at all four wing-tips and fitting hinged flaps which were pulled down on the lower side. They gave the lift which was needed to put the machine upright but they caused drag on the lifting side, and sometimes pulled the machine round so that the wing lost its lift and dropped and crashed.

Curtiss, in America, instead of cutting away the trailing edges, fitted his flaps on the struts between the upper and lower wings. As the

control was pushed over it raised the leading edge of the flap on one side and depressed the other, so that one wing was raised and the other was depressed. This was a good control, for it balanced the drag on each side, but the control wires set up a lot of resistance.

These flaps, which were in themselves little wings, were called *ailerons*, from the French word *aile*, a wing.

The aileron principle is used on most aeroplanes to-day. But we know so much more about the shape of aerofoils that a very small motion of the aileron produces a very large effect on the wing. In modern aeroplanes the ailerons are inter-connected by a system which was first used in the De Havilland machines, and is called differential aileron control.

One aileron is pulled down and lifts the wing on that side, and puts on a certain amount of drag. The other aileron is lifted, tends to depress the wing on that side, and also sets up drag which balances against the drag on the other side and so the machine keeps straight.

Our official dictionary defines "aileron" as "a flap at or near the wing-tip and designed to impart a rolling motion to the aerodyne by their differential rotation."

I had better interpret the official definition—

an aerodyne is "a generic term for aircraft which deprive their lift in flight chiefly from aero-dynamic forces."

The word aircraft itself describes "all air-supported vehicles."

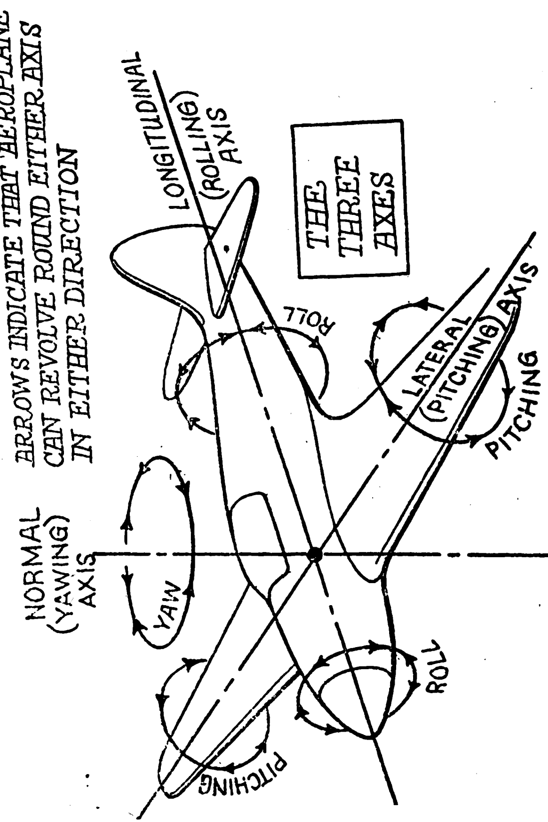

ARROWS INDICATE THAT AEROPLANE
CAN REVOLVE ROUND EITHER AXIS
IN EITHER DIRECTION
LONGITUDINAL
(ROLLING)
AXIS
THE
THREE
AXES
ROLL
LATERAL
(PITCHING)
AXIS
PITCHING
NORMAL
(YAWING)
AXIS
YAW
ROLL
PITCHING

FIGURE 7

CHAPTER SIX

The Tail Unit

What we call the tail unit, or the tail assembly, which consists of the tail-plane, or stabilizer, and the vertical fin or fins, and the elevator-planes, and the rudder or rudders, does the same job for an aeroplane as the tail-feathers do for an arrow, or a bird, it helps to keep it straight.

The function of the tail-plane is to act as a trimmer or damper on the up-and-down or pitching motions of the machine.

Similarly, the fixed fin acts as a damper on the directional movements of the machine. If the tail swings over to one side then the whole machine starts to slide sideways, and the air through which it is progressing hits the fin on that side and knocks it back again. If it swings too much in the other direction then it gets a whack on the other side which straightens it out again.

If an aeroplane has a well-shaped fuselage the air-streams are led smoothly towards the tail, and then if the tail-plane is built smoothly into the fuselage, the swinging from side to side is hardly noticeable.

This swinging from side to side is usually called yawing. Any sailor-man knows what it means. Officially it is described as "angular motion about the normal axis," which is "a straight line through the centre of gravity at right-angles to the longitudinal axis in the plane of symmetry." But an aeroplane may not yaw round its centre of gravity, it may yaw round a vertical line through the imaginary point on which the aeroplane tends to yaw sideways—otherwise the centre of side-pressure, which ought to be on the centre of gravity, but seldom is.

TURNING

A rudder is fixed on the trailing edge of the fin. Its purpose is primarily to make the machine yaw. For example if the machine be flying straight ahead and you kick the rudder over to the right, the air-streams hitting the right side of the rudder will push the tail over to the left. This will make the machine swing its nose to the right, and the whole aeroplane will tend to slide sideways through the air in the direction in which it was going, but with the left wing in front.

That will blanket the right wing somewhat,

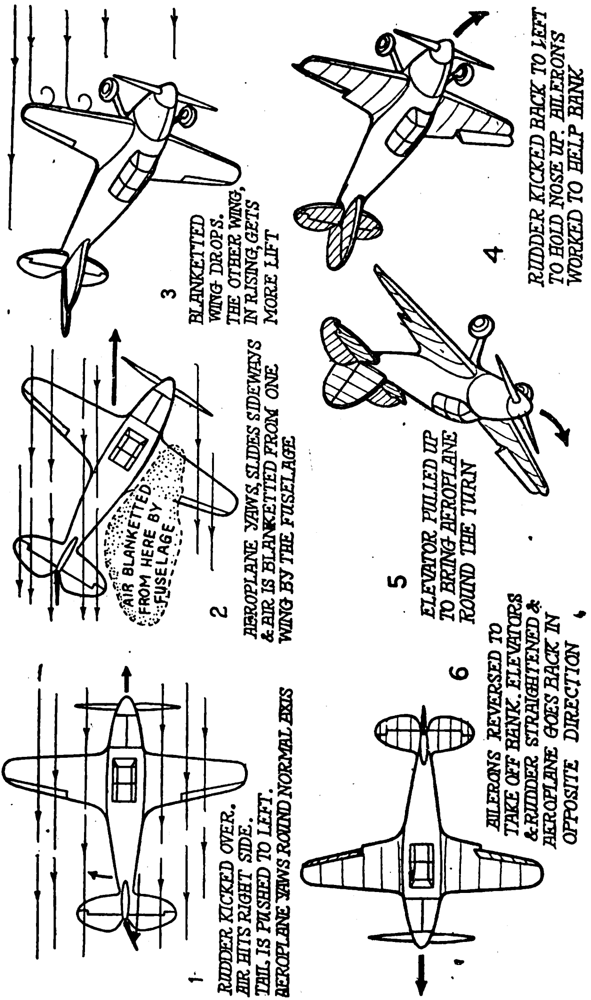

1
RUDDER KICKED OVER.
AIR HITS RIGHT SIDE.
TAIL IS PUSHED TO LEFT.
AEROPLANE YAWS ROUND NORMAL AXIS
AIR BLANKETTED FROM HERE BY FUSELAGE
2
AEROPLANE YAWS, SLIDES SIDEWAYS
& AIR IS BLANKETTED FROM ONE
WING BY THE FUSELAGE
3
BLANKETTED
WING DROPS.
THE OTHER WING,
IN RISING, GETS
MORE LIFT
4
RUDDER KICKED BACK TO LEFT
TO HOLD NOSE UP. AILERONS
WORKED TO HELP BANK
5
ELEVATOR PULLED UP
TO BRING AEROPLANE
ROUND THE TURN
6
AILERONS REVERSED TO
TAKE OFF BANK. ELEVATORS
& RUDDER STRAIGHTENED &
AEROPLANE GOES BACK IN
OPPOSITE DIRECTION

FIGURE 8

because the fuselage will be sliding sideways through the air. And that will take some of the lift out of the right wing, which will drop, while the left wing progresses and lifts. Then the machine will bank over to the right and you have the beginnings of a right-hand turn—also if you are not careful you have the beginning of a right-hand spin.

When the turn does begin the outer wing progresses faster than the inner wing, and gets more lift and therefore tends to turn the machine over towards the inside of the turn. And then the lower wing on the inside has to be lifted up by using the aileron to prevent the turn from developing into a tight spiral and so into a spin.

The orthodox method of turning is to pull the aeroplane over on to one side with the ailerons, and then pull back the stick so that the elevators go up and pull the machine round by pushing the tail towards the outside of the turn and so pointing the nose towards the inside of the turn.

When the pilot wants to come out of the turn he pulls the machine into a horizontal position with the ailerons, and then flies flat with the elevators. All the fin does is to keep it from yawing.

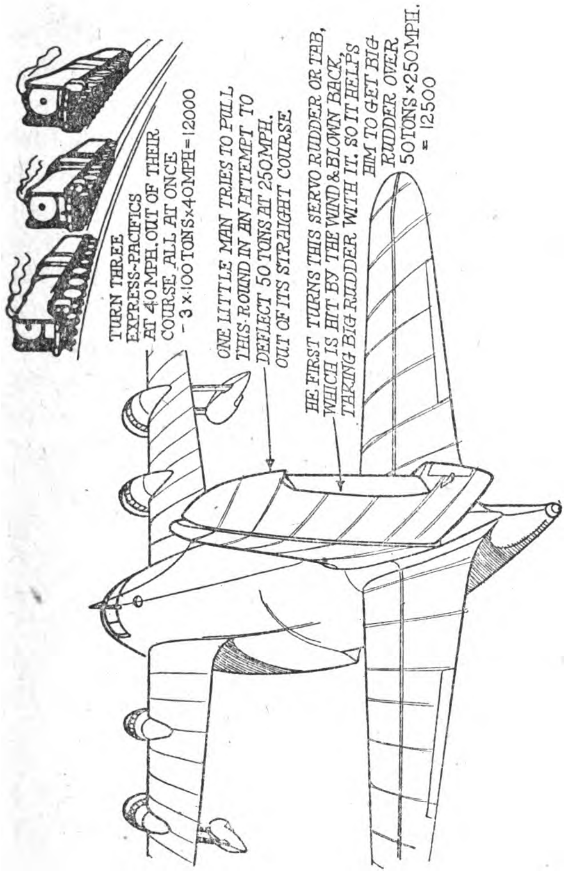

TURN THREE
EXPRESS-PACIFICS
AT 40 MPH. OUT OF THEIR
COURSE ALL AT ONCE
- 3 x 100 TONS x 40 MPH = 12000
ONE LITTLE MAN TRIES TO PULL
THIS ROUND IN AN ATTEMPT TO
DEFLECT 50 TONS AT 250 MPH.
OUT OF ITS STRAIGHT COURSE
HE FIRST TURNS THIS SERVO RUDDER OR TAB,
WHICH IS HIT BY THE WIND & BLOWN BACK,
TAKING BIG RUDDER WITH IT. SO IT HELPS
HIM TO GET BIG
RUDDER OVER
50 TONS x 250 MPH.
= 12500

FIGURE 9

On some very big machines the rudder is so massive that holding it in one direction or even moving it momentarily is heavy work. So "trimming-tabs" were invented, as an alternative to auxiliary mechanism, or servo-motor, to help the pilot. These tabs are like miniature rudders on the trailing edge of the rudder itself. When the trimming tab is pulled to the right the air pressure naturally pushes the rudder to the left. The air hitting the rudder on its left side starts a yaw to the right, and so the whole machine turns to the left. Similar tabs are used on elevators and ailerons of big aeroplanes. These tabs may be set in a fixed position to keep the machine in trim in one direction.

CHAPTER SEVEN

The Aero-Dynamics of Manœuvres

(A) We have now dealt with the streamlining of bodies generally, with particular application to the streamlining of the fuselage, hull or body of aeroplanes.

(B) We have dealt with the camber and lift of an aerofoil.

(C) We have discussed the effects of the control surfaces, namely, the ailerons, the rudder and the elevators, but only in relation to ordinary straight flying.

Now let us consider some of the facts and factors of the aeroplane, aerodyne, or flying machine as a whole.

I must assume for the purposes of this discussion that all readers of this book know what the Centre of Gravity of a body is—commonly called the C.G. To put it in a most elementary way, if you could attach an invisible cord to the Centre of Gravity of a body, which cord should be able to pass through the substance of the body without cutting it, the body would remain in balance from that centre-point no matter what position you put it in.

Try to balance yourself on a rail with your feet sticking out one side and your head the other, when lying horizontally. The result is surprising.

As any finite body has a Centre of Gravity, so every aeroplane has a Centre of Lift. This is more often called the Centre of Pressure—or commonly C.P. It is defined officially as "the point of intersection of the resultant aero-dynamic force and the chord-line of an element of an aerofoil." That refers actually to the Centre of Pressure of a single aerofoil and not to the Centre of Pressure of a whole aeroplane, in which the C.P. has to average out its position between the C.P., or Centre of Lift, of each wing, and the accompanying upward or downward pressure of the fuselage, according to its shape, and the aero-dynamic effect of the slip-stream of the air-screw (of which more later) and the aero-dynamic effect of the Centres of Pressure of the tail-plane and elevators.

To go back to the analogy of the Centre of Gravity, the Centre of Pressure is the point from which the aeroplane is suspended on the air as if by a string.

If the machine is what is commonly called nose-heavy, that is if the Centre of Gravity of the whole machine is in front of the Centre of

Pressure, then the nose will tend to drop, and the machine, if left alone, will dive more or less steeply according to the position of these two important centres.

This can be corrected by pulling the stick back and pulling up the elevators; or by pulling up the tail-plane adjustment. This puts air-pressure on the top surface of either or both and so forces the tail down, using the centre of pressure as the axis of the see-saw—and thus forcing the machine to fly level. But doing that wastes power by putting pressure on the upper surfaces.

Similarly, if the Centre of Pressure of an aeroplane is in front of the Centre of Gravity, then the machine becomes tail-heavy and the machine has to fly with the elevators held down, whether by the control-stick or by the trimming-tabs.

That is less inefficient than flying a nose-heavy machine with the elevators up. The tail-end of the machine is being lifted by the elevators or tail-plane, thus carrying some of the weight which would otherwise be carried on the wings. But in the nose-heavy machine the air force exerted on the top of the tail-plane and on the top of the elevators forces the tail down and adds to the weight on the wings, and so increases the wing-loading.

STABILITY

Stability of a ship on the sea or of an aeroplane in the air does not mean staying put, it means coming back to the proper position when disturbed. And stability in an aerodyne means a natural inclination to come back to an upright flying position if upset.

An aeroplane may be either unstable, negatively stable, or positively stable.

When it is unstable the Centre of Gravity and the Centre of Pressure and the stabilizing surfaces, which are the tail-plane and the wingtips and fin, are so arranged that if the machine is left alone it will either roll over sideways out of control, or will dive on a path which becomes steeper and steeper as it goes down, or it will throw its nose up and its tail down, and the machine will slide down backwards.

A negatively stable machine will fly all right until it is disturbed by an air current and then it will behave improperly until the pilot brings it back into the proper flying position.

A positively stable machine will return to a proper flying position if left alone. How long they take to come back depends on a great many things, such as the speed of the aeroplane, and the size of the surfaces on which it depends for its stability.

Incidentally, there are two sorts of stability, commonly so called. One is automatic stability and the other is inherent stability.

Automatic Stability is got by fitting the machine with some form of automatic control machinery such as the automatic pilot—commonly known in the Air Force as "George" and in America as "Iron Mike." This is an arrangement of gyroscopes, fitted in the pilot's office, which are connected to the moveable controls—the ailerons, rudder and elevators—and if the aeroplane deviates from a straight line, or an even keel, then the gyroscopes automatically take charge of the controls and keep the machine right side up.

Inherent Stability, which is the tendency or ability of the machine to come back to the right position of its own accord, is got by so designing its surfaces that they right it in the same way as a lifeboat rights itself in the sea.

The official scientific definition of Stability is—"The quality whereby any disturbance of steady motion tends to decrease. A given type of steady motion is stable if the aircraft returns to that state of motion after the disturbance, without movement of the controls by the pilot." I hope that is clear.

In the early days of flying, when we began to know a little about stability, somebody pro-

duced the theory of the Triple Vee—which had nothing to do with three dots and a dash.

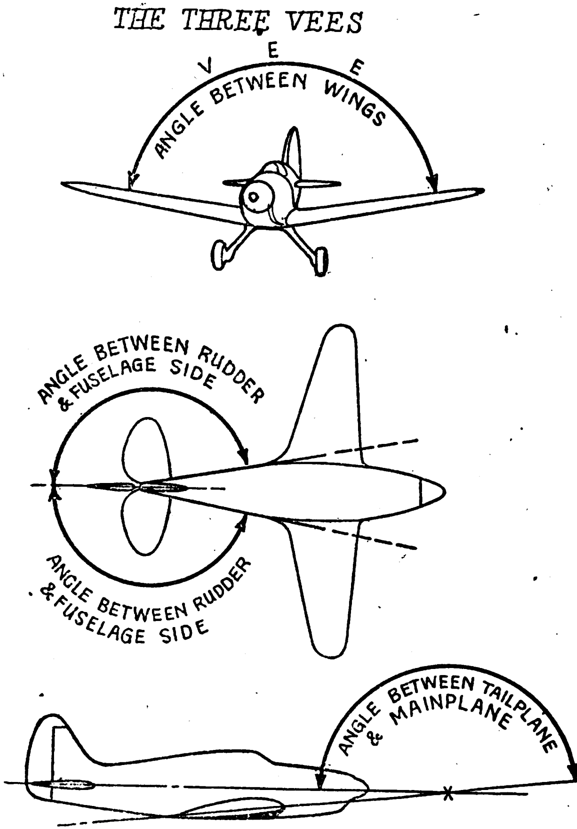


FIGURE 10

To have Lateral Stability so that the aeroplane will roll sideways and come back to an even keel, one must have a Vee between the wings. That is more scientifically called a Dihedral Angle"—the wing-tips are higher than the roots or butts where they join the fuselage.

To have Longitudinal Stability so that the aeroplane will fly level if it has started pitching fore and aft, you must have the longitudinal V between the angle of attack, or incidence, of your wings and the angle of your tail-plane and elevators.

To have Directional Stability, that is, to fly straight, you must have a similar V on each side of the aeroplane, between the sides of the fuselage and the fin and rudder.

LONGITUDINAL STABILITY

Let us take Longitudal Stability first, because that is probably the most easily understood. Assume that the angle of the wings is such that the machine will fly steadily level. The tail-plane and elevators, assuming that the elevators are floating loosely and are not being pushed about by the pilot, should be in a neutral position, neither lifting the tail up nor pushing

it down, and at a smaller angle to the air than the wings—and so form a fore-and-aft Vee.

Now supposing that the aeroplane meets a gust which increases the lift of the wings and throws the nose up, the same gust just afterwards will hit the tail, which, because its angle has been increased by the increase of the angle of the wings, also increases its angle and gets a correspondingly increased lift; which, because it is applied at the end of a long lever—that is, the fuselage—lifts the back of the machine up and puts the wings into their proper position again.

Similarly, if the nose should drop into a downward current, or into a current which has less upward effect, the wings will tend to lose lift, and the front of the machine will drop. Then the tail will run into that same air and, because it is at a less angle than the wings, it will lose its lift, or possibly have pressure applied on the top surface, which will tend to throw the tail down.

LATERAL STABILITY

In much the same way, when there is a V between the wings from side to side, if the machine rolls over to one side the wing on the

lower side will then be flying level and so will have an increased lift, whereas the wing on the upper side will be slanting up into the air and will lose a certain amount of its lift and tend to drop.

Thus longitudinal and lateral stability depend on the Centre of Gravity of the whole aeroplane being the right amount below the Centre of Pressure. If the Centre of Gravity be down too low then the whole aeroplane may tend to swing like a pendulum below the Centre of Pressure and become hard to control.

DIRECTIONAL STABILITY AND KEEL SURFACE

Directional stability is got in much the same way. The fuselage is thick forward and tapers away aft so that the air-streams, after they have closed in on the streamline shape, run inwards towards the fin and rudder. There the fin forms a V with the air-flow, so that if the machine yaws to one side the increased angle of the tail-plane tends to throw it back.

That may be an unscientific explanation but I hope it will make clear how an aeroplane is made inherently stable.

Furthermore, just as the lifting or horizontal surfaces of an aeroplane, the wings and the

tail-plane and the elevators have between them a centre of pressure on which the whole aeroplane is balanced, so the side-areas, or vertical surfaces, of the aeroplane, which may be called Keel surfaces, have a centre of pressure round which the machine will tend to spin as if it were mounted on a vertical rod or a pivot.

These Keel surfaces are complicated. The fuselage itself may vary in shape considerably according to the size and shape of the engine which is stuck in the nose. A long in-line engine increases the forward side-area enormously. A flat-sided fuselage, very deep from top to bottom, acts quite differently from a long thin rounded fuselage which might have the same area on a drawing.

My friend, Group-Captain D. C. M. Hume, who is Chief Technical Officer of the Royal Canadian Air Force, and was one of our best technicians in this country for many years, has recently produced a book in Canada on Elementary Aero-Dynamics, which he calls *A Text-Book for Ab-Initio Use*. His students have evidently had considerable training in mathematics, and are much senior to those for whom this book is intended. But he has a way of putting some of his scientific truths quite simply.

Of Stability he says: "A very stable aircraft is not very manœuvreable. The two attributes are opposed and the degree of stability built into an aircraft is governed by the use to which it is to be put. Thus the stability of single-seater fighters, which must be very manœuvre-able, should be low and that of the bombers, which must be steady aiming platforms, high."

Of directional stability he says that if the keel surface be arranged to have its Centre of Pressure, or what one might call the pivot, aft of the aircraft's centre of gravity, it will have a restoring action, in "crabbed" flight—that is, if the machine be thrown off its direct course and begins to slide sideways through the air, or yaw.

CHAPTER EIGHT

Airscrews

In considering what an aeroplane does and how it does it we have had to assume that even the youngest reader knows that an aeroplane is pulled along by the nose, or pushed from behind, by an airscrew, and that the airscrew is driven by an internal combustion engine.

The engine or aero-motor is outside the scope of this book altogether so we must go on assuming that the reader knows all about it. I prefer the word motor to engine, because in all languages motor means motor, but in some languages engine means a whole apparatus, as we ourselves speak of a tank or an aeroplane or a Roman catapult as an engine of war.

An airscrew is only two aerofoils of the same kind facing in opposite directions, stuck on to one shaft, which itself is carried on another shaft at right angles, so that the whole outfit revolves in a vertical plane on its horizontal shaft. Each aerofoil as it goes round tries to lift, but as it is placed vertically its lift is horizontal so that you have two aerofoils dragging the other aerofoils and the body of the machine through the air.

Commonly the airscrew is called the propeller, whether it pulls or pushes. Strictly only a pusher should be called a propeller—one which pulls should be called a tractor-screw. If you stick to pusher and tractor nobody can mis-

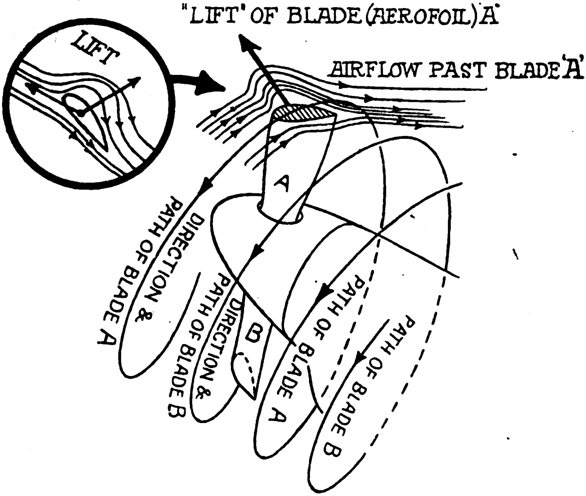


FIGURE II

understand what you mean. But the aerodrome slang word "prop" is short and convenient. Also, if one regards it not as short for propeller, but as the thing which props the machine up in the air, it is sensible.

To get the highest efficiency out of the whole aeroplane the pitch of the airscrew, which

depends on its angle of attack to the air, should be such that at the revolutions per minute given by the motor the speed of the aeroplane through the air should be that at which the wings and the fuselage and the tail unit are flying most efficiently—that is to say, with the least waste of power on dragging the machine through the air faster than it wants to go. Remember that if you drag a streamline body and a set of aerofoils through the air so fast that the air streams become turbulent, you are wasting power.

Every aeroplane has one speed at which it is most economical—which is called the optimum speed. If you fly more slowly the wings and the fuselage fly at a bad angle and although you use less power, your slowness is out of proportion to the power used. On the other hand, if you try to pull it through the air faster than its optimum speed it costs you more in power and petrol.

Here I cannot do better than quote Group-Captain Hume again. He says: "An aircraft to achieve steady flight must continue on its set course, on an even keel, without deviation up, down or sideways. In this condition it is said to be *in equilibrium*."

"Equilibrium is a momentary state of the

aircraft in flight and premises" (or assumes) "that all *the four forces of flight* are in balance.

"To establish any desired state of equilibrium, that is at any attitude or speed, adjustments of the methods of interbalancing the forces have to be made by the pilot. The aircraft has to be trimmed and it is then said to be *in trim*."

THE FOUR FORCES

These four forces may be considered thus:

(A) The Weight of an aircraft acts, as we have already seen, through a fixed point called the Centre of Gravity.

(B) Drag, or head-resistance, acts through a fixed point called the Centre of Drag. This is, as one might say, an imaginary point which is arrived at by taking an average of all the different frontal areas which one sees when looking at the aeroplane head-on. Really it includes more than that, because in taking the average of all the forces which put drag on an aeroplane, many of them are actually the turbulence of the air-waves set up by different parts of the aeroplane and fighting with one another. But that is going rather a long way towards being scientific.

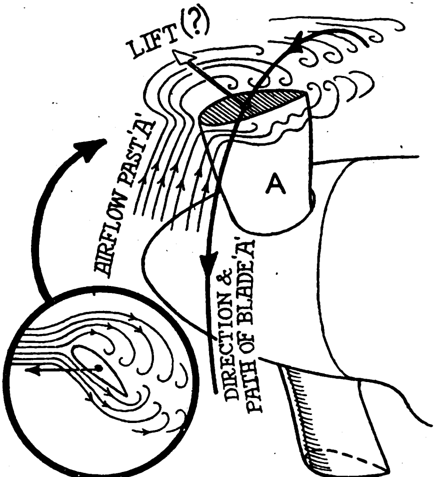
(C) The Thrust, which is the power delivered by the airscrew to its horizontal shaft, acts through a fixed point which is called the Centre of Thrust. Here please notice that the airscrew shaft, whether it is actually part of the engine shaft or is a separate shaft driven by gearing, has a double job. It has to turn the airscrew to grip the air and to transfer to it the power from the engine, and it also has to transmit the tractive or propulsive power which pulls or pushes the whole machine through the air.

(D) The Lift acts through the Centre of Pressure. This, although one has to treat it as a fixed point when discussing the balance of the aeroplane in relation to the Centre of Gravity, is in fact a variable point because it moves backwards or forwards according to the angle at which the aerofoil and the fuselage and the tail unit, attack the air.

THE PRINCIPLE OF THE AIRSCREW

The principle of an airscrew is simply that of an ordinary metal screw which screws its way into wood. If it is highly efficient it will screw steadily into the wood or air which is immediately round the blade or thread.

If an airscrew be inefficient, instead of screwing its way steadily forward, and pulling the aeroplane along, it will churn up the air and throw it back over the aeroplane. To be highly



BLADE 'A' IS AT TOO COARSE PITCH SO IT STALLS

FIGURE 12

efficient a blade of an airscrew should be so shaped that the air slides smoothly over it as it should slide over a well-shaped aerofoil.

People often think that an airscrew is a form of rotary fan. The difference between an airscrew and a fan is precisely the difference

between a woodscrew going steadily forward through the wood and an auger, which cuts its way into the wood slowly so that it ejects chips of the wood behind it.

The pitch of an airscrew is not exactly the same thing as the angle of attack of an aerofoil, though closely related to it. One talks of a coarse or fine pitch just as one talks of a coarse or fine thread on a screw.

The pitch is the distance which the tip of the airscrew would travel forward horizontally, in one complete revolution of the shaft if there were no slip in the air. If the blade, or aerofoil, of the airscrew have a high or coarse pitch, that is to say, if the angle of attack be big, then the blades will travel forward a greater distance in one revolution than if they have a fine pitch or small angle of attack.

TRIM

Having established our Four Forces of Flight, we find that, as friend Hume says, there is no guarantee that the Centre of Drag is in the same fore-and-aft line as the Centre of Thrust.

Often the Centre of Thrust, that is, the line of pull of the airscrew—or the average line of pull of two or three or four airscrews in a

multi-motor aeroplane—is not vertically along the same horizontal line as the Centre of Drag. When these two forces do not coincide the result is what is called a couple.

This tends to pull the machine over on its nose or make it feel nose-heavy, if the Centre of Thrust be higher than the Centre of Drag, or to pull the nose up and make the machine feel tail-heavy, if, as happens as often, the Centre of Thrust be below the Centre of Drag.

If the Centre of Thrust be above the Centre of Drag, then the remedy is to cock the tail-plane up, at a negative angle, so as to force the tail down and keep the nose up, which is bad. Also, if the motors cut out suddenly the tendency of the machine is to throw its nose up when the downward pull of the thrust is removed. On the other hand, if the thrust be below the centre of drag, then if the engine should stop the tendency will be for the nose to drop and so the machine will dive.

A designer has to allow for balancing these forces and for giving the pilot plenty of control over them in case the engine does stop.

WASTE IN THE SLIP-STREAM

All these forces are complicated by the fact

that the airscrew rotates so that, in a normal single-motor aeroplane, on one side the blades are always going down, and on the other side the blades are always coming up. No humanly made mechanism is 100 per cent. efficient, consequently, although theoretically an air-screw should screw its way through the air without wasting power, in fact it also throws back, like a fan, a considerable amount of air. This is known as the slip-stream. Naturally the greater the slip-stream the more wasteful the aeroplane. And obviously a wind-stream of many m.p.h. pounding down on top of one wing of an aeroplane and hitting up at as many m.p.h. under the other wing, cannot make for efficiency.

Another effect of the single airscrew is what is called torque, which is simply twist. When an aeroplane's motor is running on the ground the air-screw acts as a very inefficient fan and not as an airscrew, and while the aeroplane is gathering speed on the ground, the airscrew is still acting more as a fan and less as a screw.

As the blade pushes its way down through the air it meets with strong resistance, and as the aero-motor goes on twisting the airscrew shaft, the result is that the whole aeroplane has a tendency to turn over in the opposite direction.

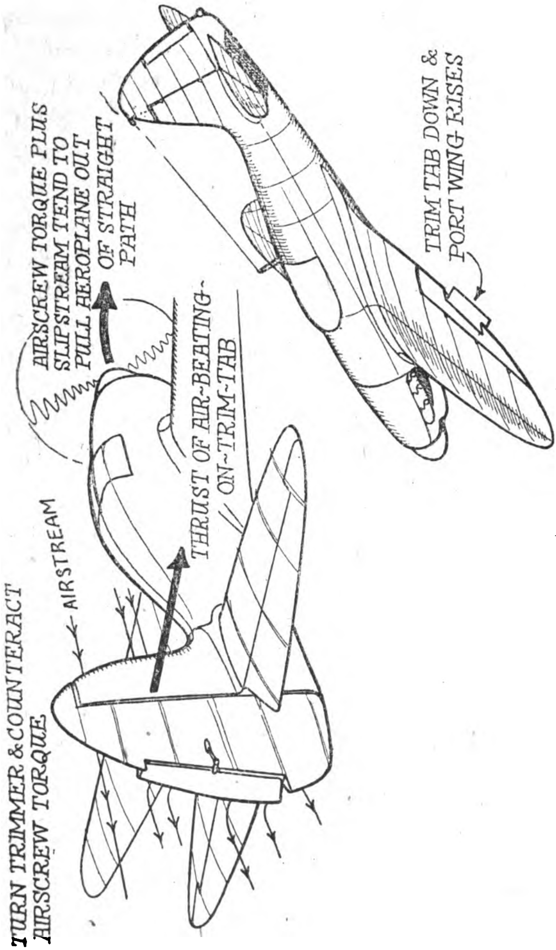


FIGURE 13

TORQUE AND SLIP-STREAM

If one had a very large airscrew and very small wings the aeroplane would go round the airscrew instead of the airscrew going round the aeroplane. And if you watch a motor "running up" on the ground you will see that when it opens up suddenly the wing on one side will try to bend over and touch the ground.

In the days of low-powered motors and very large aeroplanes the torque effect did not matter much, but in these days of small aeroplanes and big motors it becomes considerable.

There are already in various experimental stages a number of devices which enable one motor to drive two airscrews on the same axis, on two separate but concentric shafts in opposite directions. These are commonly called "contra-props." The force of one screw tends to turn the aeroplane over on one wing-tip while the force of the other tends to turn it over on the opposite wing-tip. The two cancel out and there is no torque effect on the aeroplane itself at all.

The Italians did this first when they put the World's Speed Record up to 480 m.p.h. by putting one engine behind the other, running them in opposite directions, and gearing them to separate airscrew shafts one of which ran inside the other. But the idea goes back to 1909. And a famous British aircraft manufacturer has

had flying since 1939 an excellent system of driving contra-props with very high power.

If contra-props were commonly used, less experienced pilots could fly much smaller aeroplanes with more powerful motors and consequently at greater speed, because of the absence of torque.

Credit for the first contra-prop should be given to Mr. Howard Wright, who showed one on a box-kite at Olympia in 1909. And in 1936 Mr. Frits Koolhoven, the famous Anglo-Dutch designer, showed the first modern single-motor contra-prop at the Paris Aero show. It was never developed because of industrial troubles in France where it was to be made.

CHAPTER NINE

Manœuvres

Strictly speaking, manœuvres belong to the title, "How to fly an aeroplane," rather than "How an aeroplane flies," but simple aerodynamic explanations of some of them are worth noting.

First of all take the simplest of all manœuvres, the Loop. An aeroplane flies along horizontally. The pilot generally dives a little to pick up more speed by adding the force of gravity to his airscrew thrust. Then he pulls the stick back and pulls the elevator up. That pushes down the tail of the machine, which begins to climb. Then instead of putting the stick forward a little and so continuing climbing up an inclined path, the pilot pulls the stick back still more, so that the tendency of the machine is to fly round in a circle.

If the pilot puts his stick forward as he goes up the loop the machine will try to straighten out its line of flight in whatever direction the nose may be pointing. It may stand still in the air and fall back on its tail, or, if it is halfway round the loop, it will try to stop on its back

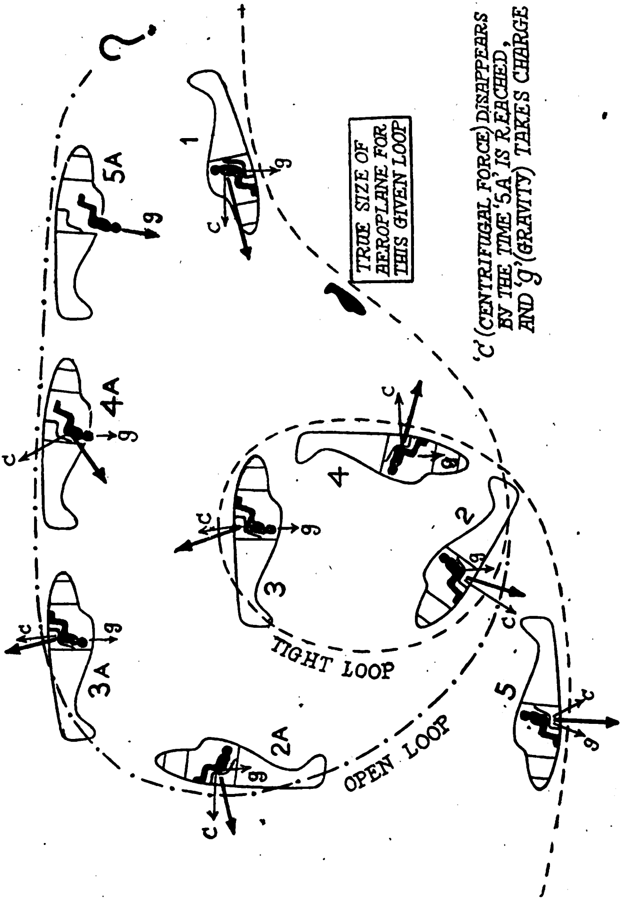

TRUE SIZE OF
AEROPLANE FOR
THIS GIVEN LOOP
'C' (CENTRIFUGAL FORCE) DISAPPEARS
BY THE TIME '5A' IS REACHED,
AND 'g' (GRAVITY) TAKES CHARGE
1
2
3
4
5
2A
3A
4A
5A
TIGHT LOOP
OPEN LOOP

FIGURE 14

but will probably merely drop its nose and dive upside down.

In looping, Centrifugal Force, the force which tries to keep any body moving in a straight line, when it is being held on a curved path, replaces the force of gravity. So the air streams flow properly over the wings. Centrifugal Force is only the mass of the body concerned objecting to being made to change its course when moving.

ABOUT THE CENTRE OF PRESSURE

The shift, or movement, of the Centre of Pressure (generally called the C.P.), on an aerofoil, or in a complete aeroplane, which is caused by alteration in the attitude of the aeroplane or of the aerofoil alone, is difficult to explain in words or even in sketches. This shift of C.P. is important because the trim of the machine, and the control of it, is affected greatly by the relative positions of the Centre of Gravity and the Centre of Pressure.

To get some idea of what the shift of the Centre of Pressure means, consider an aerofoil of quite simple section flying level, or held level in a wind-tunnel. According to the camber of the upper surface and the contour of the lower

surface the Centre of Pressure will be in a certain place, and that will be generally somewhere about one-third of the way back from the leading edge.

Now if you fit a flap to the trailing edge and pull it down the flap itself will try to lift up the back of the aerofoil. And the resulting Centre of Pressure of the aerofoil and the flap will be farther back than was the C.P. originally.

The effect of this on a complete aeroplane is naturally to lift up the trailing edge of the wing and with it the fuselage to which it is attached. The pilot will get the impression that the machine is nose-heavy, because he has to pull his stick back and cock up the elevators to keep the tail down. But actually the aeroplane as such will not be nose-heavy as it would be, for example, if the wings were in their ordinary best positions, but too heavy a motor had been put in the nose of the machine. And yet aerodynamically the effect is practically the same.

Again, if an aerofoil be of a section which has a comparatively flat lower surface, or one in which the trailing edge curves downwards, and if the tail of the machine be forced down by the elevators to push the nose up, then the increased angle on the flat bottom of the aerofoil will bring the pressure on the wings farther

back and so put more load on the aft spar or trailing edge of the wing.

Some designers curve the trailing edges of their aerofoils upwards in what is called a "reverse curve." This curve, or "reflexed trailing edge," will take on, to limited extent, the function of a tail-surface, and provide a longitudinal Vee on the wing itself, instead of extending the Vee the whole length of the aeroplane.

THE BANKED TURN

A banked turn, like a loop, depends on Centrifugal Force defeating the Force of Gravity.

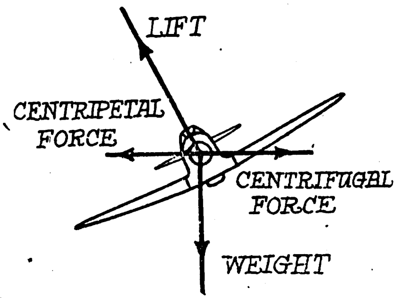


FIGURE 15

To start a turn, the pilot moves his ailerons so as to lift the wing which will be on the outside

of the turn and depress the wing on the inside. Having done that he pulls the machine round on the turn with the elevator, as explained earlier.

Centrifugal Force, which is caused by the mass of the aeroplane trying to go on in a straight line, holds it up against the air, or, more properly, holds it *out* against the air. And the air resistance, pushing against the Centre of Pressure of the aeroplane, supplies the Centri*petal* Force which the aeroplane needs to keep it in the air.

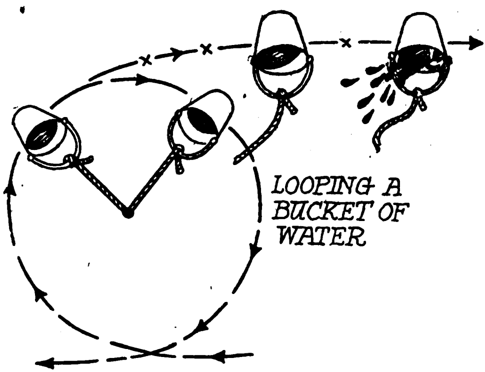


FIGURE 16

To put it simply, if you have a weight or a stone on the end of a string and whirl it round horizontally—the weight or mass of the stone trying to carry on in a straight line creates the

centri*fugal* force which tries to pull it out of your hand and keep it horizontal. But the string which prevents it from flying off supplies the centri*petal* force which pulls it round in a circle.

If you whirl the stone round vertically then you have the same forces as are applied to an aeroplane when doing a loop. You can do all this with a bucket of water on a rope. But don't let go.

Both in looping and in doing a steeply banked turn, the rudder simply keeps the fuselage on the track along which the pilot directs it with the ailerons and elevators.

THE ROLL

The roll was one of the most spectacular manœuvres developed in the early days of aviation.

One pilot, whose flying is notable for its smoothness and accuracy, told me years ago that a roll is an optical illusion. The machine does not really revolve on its longitudinal axis in a straight line, it goes round it in a sort of corkscrew. And he described a roll as being actually a "pulled-out loop."

The pilot starts by pulling up his elevator as

though he were going to start a loop, and then, using his ailerons and rudder in conjunction, makes the loop proceed rapidly sideways.

No doubt a mathematician could fill pages with formulae of the aero-dynamics which produces the roll. But pilots are satisfied with the fact that they pull the elevator, kick the rudder, and flick the ailerons in a certain direction which they learn by practice produces a roll. And a roll is a useful manœuvre in a dog-fight.

Rolls are roughly of two kinds. There is the flick roll, in which the machine revolves quite suddenly, and there is the barrel roll in which the machine definitely does go round and round on a corkscrew path.

THE SPIN

Spinning is another manœuvre which is very useful in a fight, but it is unpleasant when it cannot be controlled.

I cannot find a better description of the aerodynamics of the spin than that of my friend Group-Captain Hume. He describes it thus: "An aircraft is flying level near the stall. A disturbance is induced (usually by the pilot on purpose) in roll. The descending wing, that is the lower wing, stalls."

"Auto-rotation," by which he means rolling round the longitudinal axis, follows, and as a result the lift weakens and an inward side-slip starts. This is resisted (A) ineffectively by the dihedral angle between the wings, because of the strength of the rolling movement over which it has no control, and (B) by the keel surface, that is the side area of the machine, and fin. He might have added the rudder also, but the fin and rudder are included as one factor in this case. The action of the fin and rudder induces a yawing movement and so a spiral downward path is established.

This spiral path tends to keep the inside wing stalled and serves to retain the autorotation. The drag of the inner wing keeps the nose of the machine towards the vertical axis, and introduces an automatic yawing couple, or force. The two auto-couples, rotation and yaw, are the two "forcing" couples which generate a spin.

When the spin starts there is a body of considerable weight, the whole machine, rolling and yawing at the same time. Consequently a gyroscopic couple, or force, is set up which "tends to precess the nose up and hold the aircraft in the spin." The precession of a gyroscope is outside the scope of this book, so I can

only say that it is the force which in a gyroscope (every revolving wheel is a gyroscope) tends to alter the angle of the axle or axis on which the wheel or gyroscope is revolving if the plane of revolution of the wheel be altered.

Group-Captain Hume says that "if the two motions are carried out at the same rate then, assuming for the moment that the aircraft does not descend thereby, the combined effect is that the aircraft describes a cone in space, nose down, with the lateral axis remaining horizontal—that is with the Centre of Gravity as the apex of the cone."

In other words, the tail goes round and round like a flail, revolving on the Centre of Gravity. In fact, the aircraft *does* descend because of the destruction of lift by these motions.

He points out that any device such as slots, flaps, etc., which tend to prevent stalling will tend to prevent spinning, but the principal preventive is "finnage" which can kill the automatic yaw. This, he says, is responsible for the old dictum, "when in difficulties kick your rudder."

But there are aeroplanes in which even finnage will not stop spinning. And even the greatest mathematicians have not yet discovered how to make certain in the design stage that an aeroplane will not spin. The

solution of the puzzle at the finish comes back to the test pilot.

EFFICIENCY OF AEROPLANES

The efficiency of an aeroplane may be measured by the amount of work you get out of it in proportion to the amount of power you put into it. The work which an aeroplane does can be expressed either in load carried or in speed. And in a fighting machine the rate of climb represents useful work done, because getting up to your enemy's level is more important than being as fast as he is when you get there, because you can dive on him, thus adding Nature's power, Gravity, to your own engine-power. And in a general way the machine which has the better climb is the more manœuvreable.

Now climb depends on lift, the greater the lift of the machine the better the climb. But as Group-Captain Hume says, "Drag is the price we pay for lift. Consequently the more lift that can be obtained for a given drag, the better the arrangement." Therefore, calling Lift L and Drag D, the ratio L/D is an indication of the efficiency of an aerofoil. It represents the proportion of useful lift to unprofitable drag.

Here a rough statement of the effect of camber on aerofoils is worth while.

Thick camber, that is high from bottom to top, has a high L and a high D, and a low L/D, but the high D may be worth while for the sake of the high L.

Thin or low camber has a low L and a low D, and perhaps a high L/D at high speed.

Concave camber on the lower surface gives higher L and somewhat higher D, and improved L/D.

Convex camber below gives less L and less D and generally improved L/D.

All these things depend on the precise curvature of the camber above and below and whether they marry-up or match one another. That is why some wing-curves which look good turn out to be bad.

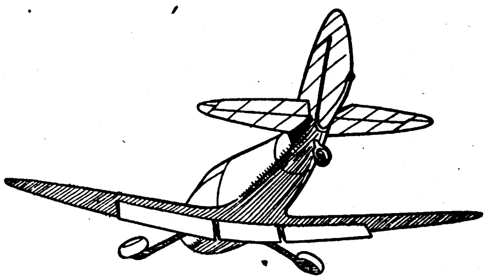
Generally speaking, high camber thick wings are weight-lifters, but make slow machines.

Low camber thin wings are best for fast light machines. Concave under-surfaces increase weight-carrying at the cost of a little speed. Convex undersides add speed to weight carriers but give away some weight-lifting ability.

One can apply the same remarks to the streamline shape of the fuselage or any other body. Fat short sections will hold more but put

up more drag. Thin sections, provided they are the right shape, give increased speed, but hold less.

At the finish the designing of a good aeroplane is a matter of experience and eye and inspiration. But plenty of experienced men, pioneers of aviation, cannot design a reasonably decent aeroplane. And a young man with far less experience may design very efficient aeroplanes. That is why there is always hope for youngsters who come into the aircraft business to work their way up and become the big designers of the future.



GOOD-BYE AND GOOD LUCK!

(A take-off, with flaps still down and undercarriage retracting.)

OVERLEAF

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